Lifecycle Environmental Impacts of Alternative-Fuel Vehicles

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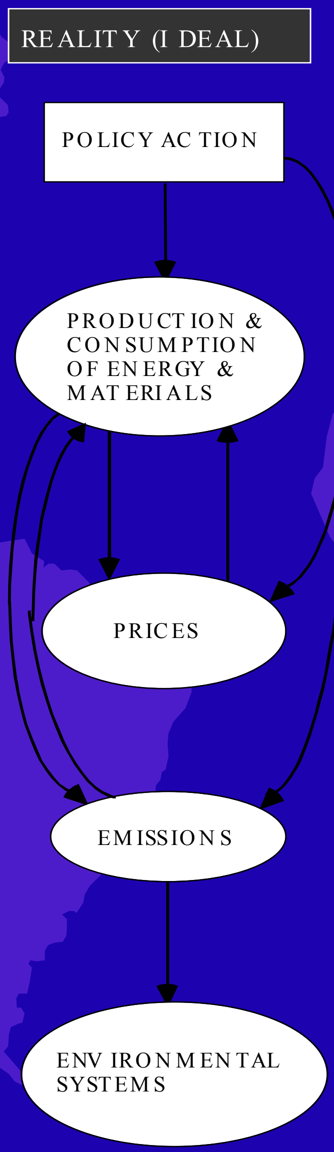
Outline

- An ideal model of life-cycle analysis (LCA)
  - Overview of strengths and weaknesses of conventional LCA with respect to the ideal
- A look at the structure of some recent LCAs
- Some result from LCAs
- Conclusions

What is the purpose of LCA?

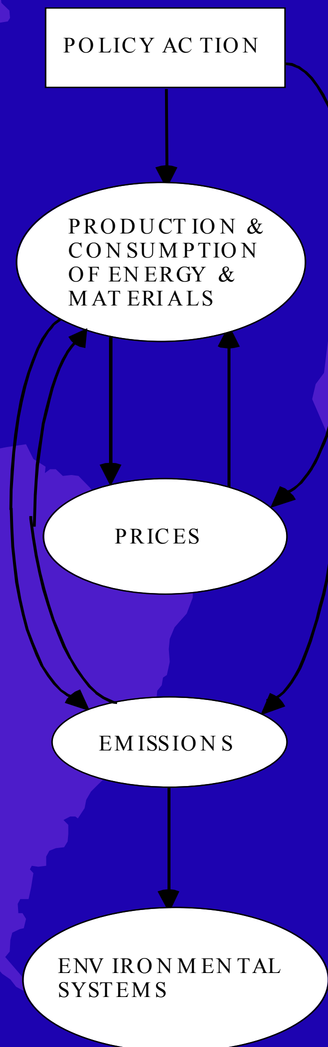
- Ideally, the purpose of LCA is to determine the difference in some environmental measure between a status quo world and the world given some proposed action (generally a policy action). This requires a careful specification of the action and then an analysis of how the world changes as a result of the action.
- In practice, however, most LCAs do not specify or analyze a policy, but just assume (implicitly) that one simple and narrowly defined set of activities replaces another.

Ideal LCA


REALITY (IDEAL)
POLICY ACTION
PRODUCTION & CONSUMPTION OF ENERGY & MATERIALS
PRICES
EMISSIONS
ENVIRONMENTAL SYSTEMS

Ideal versus conventional LCA

REALITY (IDEAL)



INCLUDED IN CONVENTIONAL LCA?

Generally not – conventional LCA does not perform policy analysis, but simply assumes that one set of activities replaces another

Ideal versus conventional LCA

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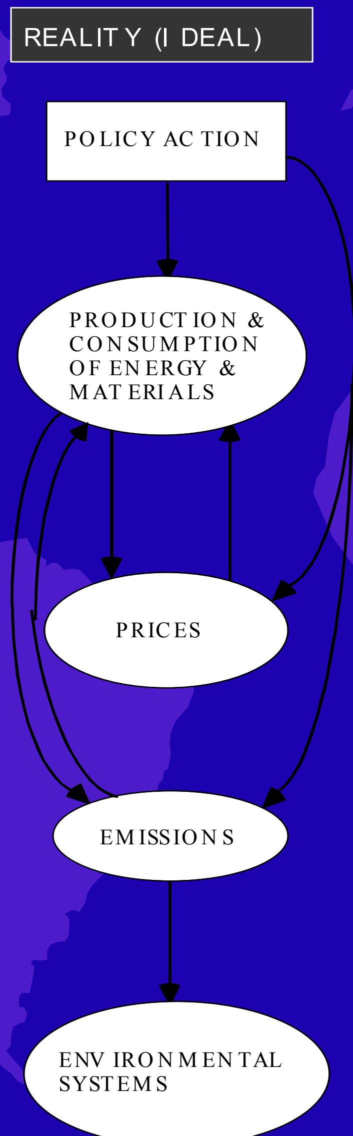

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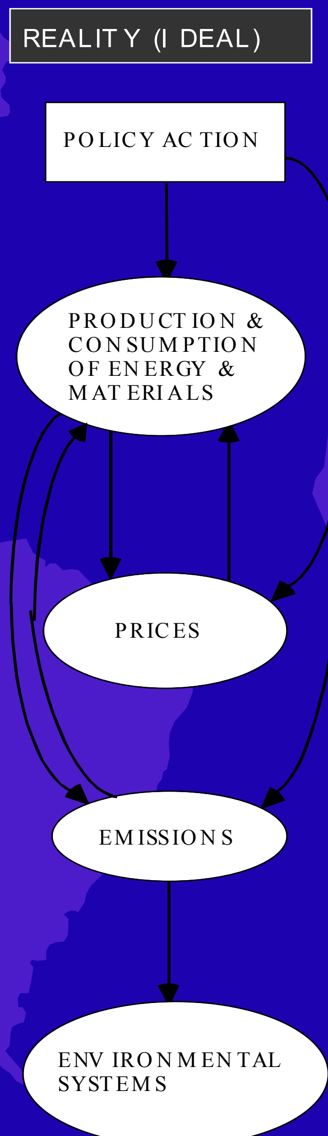

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Relationship between emissions and state of environment treated very crudely (e.g., via CEFs, some of which have serious limitations)

Recent LCAs of Fuels

- General Motors, Argonne National Lab, et al., *Well-toWheel Energy Use and Greenhouse Gas Emisions of Advanced Fuel/Vehicle Systems*, in three volumes, published by Argonne National Laboratory, June (2001). [GM-ANL U.S.]
- General Motors et al., *GM Well-to-Wheel Analysis of Energy use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study*, L-B-Systemtechnik GmbH, Ottobrunn, Germany, September 27 (2002). www.lbst.de/gm-wtw. [GM-LBST Europe]
- M.A. Weiss et al., *On the Road in 2020: A Lifecycle Analysis of New Automotive Technologies,* MIT Energy Laboratory Report EL 00-003, Massachusetts Institute of Technology, October (2000). [MIT 2020]
- P. Ahlvik and Ake Brandberg, *Well to Wheels Efficiency for Alternative Fuels from Natural Gas or Biomass*, Publication 2001: 85, Swedish National Road Administrattion, October (2001). [EcoTraffic]

Recent LCAs of Fuels (2)

- J. Hackney and R. de Neufville, “Life Cycle Model of Alternative Fuel Vehicles: Emissions, Energy, and Cost Trade-offs,” *Transportation Research Part A* **35:** 243-266 (2001). [ADL]
- H. L. Maclean, L. B. Lave, R. lankey, and S. Joshi, “A Lifecycle Comparison of Alternative Automobile Fuels,” *Journal of the Air and Waste Management Association* **50**: 1769-1779 (2000). [CMU]
- K. Tahara et l., “Comparison of CO2 Emissions from Alternative and Conventional Vehicles,” *World Resource Review* **13** (1): 52-60 (2001). [Japan]
- M. A. Delucchi, *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials*, UCD-ITS-RR-03-04, Institute of Transportation Studies, University of California, Davis, June (2003). With appendices. www.its.ucdavis.edu/faculty/delucchi.htm. [LEM]

Study aspects noted

Region	The countries or regions covered by the analysis.
Time frame	The target year of the analysis.
Transport modes	The types of passenger transport modes included. LDVs = light-duty vehicles, HDVs = heavy-duty vehicles; LRT = light-rail transit; HRT = heavy-rail transit
Vehicle drivetrain type	ICEVs = internal combustion-engine vehicles, HEVs = hybrid-electric vehicles (vehicles with an electric and an ICE drivetrain), BPEVs = battery-powered electric vehicles (BPEVs), FCEVs = fuel-cell powered electric vehicles.
Fuels	Fuels carried and used by motor vehicles. FTD = Fischer-Tropsch diesel, CNG = compressed natural gas, LNG = liquefied natural gas, CH2 = compressed hydrogen, LH2 = liquefied hydrogen, DME = dimethyl ether.
Feedstocks	The feedstocks from which the fuels are made.
Vehicle energy-use modeling	The models or assumptions used to estimate vehicular energy use (which is a key part of fuelcycle CO_2 emissions), and the drive cycle over which fuel usage is estimated (if applicable).
Fuel LCA	The models, assumptions, and data used to estimate emissions from the lifecycle of fuels.

Study aspects noted (2)

Vehicle lifecycle	The lifecycle of materials and vehicles, apart from vehicle fuel. The lifecycle includes raw material production and transport, manufacture of finished materials, assembly of parts and vehicles, maintenance and repair, and disposal.
GHGs and CEFs	The pollutants (greenhouse gases, or GHGs) that are included in the analysis of CO_2-equivalent emissions, and the CO_2-equivalency factors (CEFs) used to convert non-CO_2 GHGs to equivalent amount of CO_2 (IPCC = factors approved by the Intergovernmental Panel on Climate Change [IPCC]; my CEFs are those derived in Appendix D).
Infrastructure	The lifecycle of energy and materials used to make and maintain infrastructure, such as roads, buildings, equipment, rail lines, and so on. (In most cases, emissions and energy use associated with the construction of infrastructure are smalled compared with emissions and energy use from the end use of transportation fuels.)
Price effects	This refers to the relationships between prices and equilibrium final consumption of a commodity (e.g., crude oil) and an “initial” change in supply of or demand for the commodity or its substitutes, due to the hypothetical introduction of a new technology or fuel.

Structure of studies 1-4

Project	**GM -ANL U. S.**	**GM –LBST Europe**	**MIT 2020**	**EcoTraffic**
Region	North America	Europe	based on U. S. data	weighted to Europe
Time frame	near term (about 2010)	2010	2020	between 2010 and 2015
Transport modes	LDV (light-duty truck)	LDV (European mini-van)	LDV (mid-size family passenger car)	LDVs (generic small passenger car)
Vehicle drivetrain	ICEVs, HEVs, BPEVs, FCEVs	ICEVs, HEVs, FCEVs	ICEVs, HEVs, BPEVs, FCEVs	ICEVs, HEVs, FCEVs
Fuels	gasoline, diesel, naptha, FTD, CNG, methanol, ethanol, CH2, LH2, electricity	gasoline, diesel, naptha, FTD, CNG, LNG, methanol, ethanol, CH2, LH2	gasoline, diesel, FTD, methanol, CNG, CH2, electricity	gasoline, diesel, FTD, CNG, LNG, methanol, DME, ethanol, CH2, LH2
Feedstocks	crude oil, NG, coal, crops, ligno-cellulosic biomass, renewable and nuclear power	crude oil, NG, coal, crops, ligno-cellulosic biomass, waste, renewable and nuclear power	crude oil, NG, renewable and nuclear power	crude oil, NG, ligno-cellulosic biomass, waste

Structure of studies 1-4, cont.

Project	GM -ANL U. S.	GM –LBST Europe	MIT 2020	EcoTraffic
Vehicle energy-use modeling, including drive cycle	GM simulator, U. S. combined city/ highway driving	GM simulator, European Drive Cycle (urban, extra-urban driving)	MIT simulator, U. S. combined city/ highway driving	Advisor (NREL simulator), New European Drive Cycle
Fuel LCA	GREET model	LBST E^2 I/O model and data base	literature review	literature review
Vehicle lifecycle	not included	not included	detailed literature review and analysis	not included
GHGs [CEFs]	CO2, CH4, N2O [IPCC] (others as non-GHGs)	CO2, CH4, N2O [IPCC]	CO2, CH4 [IPCC]	none (energy efficiency study only)
Infra-structure	not included	not included	not included	not included
Price effects	not included	not included	not included	not included

Structure of studies 5-8

Project	ADL AFV LCA	CMU I/O LCA	Japan CO2 from AFVs	LEM
Region	United States	United States	Japan	multi-country
Time frame	1996 baseline, future scenarios	near term	near term?	any year from 1970 to 2050
Transport modes	subcompact cars	LDVs (midsize sedan)	LDVs (generic small passenger car)	LDVs, HDVs, buses, LRT, HRT, minicars, scooters, offroad vehicles
Vehicle drivetrain	ICEVs, BPEVs, FCEVs	ICEVs	ICEVs, HEVs, BPEVs	ICEVs, BPEVs, FCEVs
Fuels	gasoline, diesel, LPG, CNG, LNG, methanol, ethanol, CH2, LH2, electricity	gasoline, diesel, biodiesel, CNG, methanol, ethanol	gasoline, diesel, electricity	gasoline, diesel, LPG, FTD, CNG, LNG, methanol, ethanol, CH2, LH2, electricity
Feedstocks	crude oil, NG, coal, corn, ligno-cellulosic biomass, renewable and nuclear power	crude oil, natural gas, crops, ligno-cellulosic biomass	crude oil, natural gas, coal, renewable and nuclear power	crude oil, NG, coal, crops, lignocellulosic biomass, renewable and nuclear power

Structure of studies 5-8, cont.

Project	ADL AFV LCA	CMU I/O LCA	Japan CO2 from AFVs	LEM
Vehicle energy-use modeling, including drive cycle	Gasoline fuel economy assumed; AFV efficiency estimated relative to this	Gasoline fuel economy assumed; AFV efficiency estimated relative to this	none; fuel economy assumed	simple model, U. S. combined city/highway driving
Fuel LCA	Arthur D. Little emissions model, revised	own calculations based on other models (LEM, GREET..)	values from another study	detailed own model
Vehicle lifecycle	not included	Economic Input-Output Life Cycle Analysis software	detailed part-by-part analysis	detailed literature review and analysis
GHGs [CEFs]	CO2, CH4, [partial GWP] (other pollutants included as non-GHGs)	CO2, CH4, N2O? [IPCC] (others as non-GHGs)	CO2	CO2, CH4, N2O, NOx, VOC, SOx, PM, CO [IPCC and own CEFs]
Infra-structure	not included	not included	not included	very simple representation
Price effects	not included	not included (fixed-price I/O model)	not included	a few simple quasi-elasticities

The Lifecycle Emissions Model (LEM)

- Lifecycle emissions of urban air pollutants and greenhouse-gases
  - -- VOCs, CO, NOx, SOx,PM, CO2, CH4, N2O, H2, CFCs, HFCs, PFCs, individually and as CO2-equivalents
- Lifecycles for fuels, vehicles, materials, bus and rail transit
  - -- "well to wheel" lifecycle for fuels
  - -- "cradle to grave" lifecycle for materials and vehicles
  - -- upstream and infrastructure lifecycles in public transit
- Alternative transportation fuels and vehicles
  - -- LD ICEVs, HD ICEVs,LD battery EVs, LD and HD fuel-cell EVs
  - -- gasoline, diesel fuel, FTD, biodiesel (soy) methanol (NG, coal, biomass), ethanol (corn, grass, wood), CNG, LNG, CH2 and LH2 (water, NG)

Lifecycle stages in the LEM

<u>Fuels and electricity lifecycle</u>

- End use of fuel
- Dispensing of fuels
- Fuel distribution
- Fuel production
- Feedstock transport
- Feedstock production

<u>Vehicles and infrastructure lifecycle</u>

- Materials production
- Vehicle assembly
- Maintenance and systems operation
- Lifecycle of transport modes (rail, water, truck, etc.)
- Infrastructure construction

Feedstocks and fuels in the LEM

Fuel --> ↓ **Feedstock**	*Gasoline*	*Diesel*	*Methanol*	*Ethanol*	*CNG, LNG*	*LPG*	*CH2, LH2*	*Electric*
Petroleum	ICEV, FCV	ICEV				ICEV		BPEV
Coal	ICEV	ICEV	ICEV, FCV					BPEV
Natural gas		ICEV	ICEV, FCV		ICEV	ICEV	ICEV, FCV	BPEV
Wood, grass			ICEV, FCV	ICEV, FCV	ICEV			BPEV
Soybeans		ICEV						
Corn				ICEV				
Solar							ICEV, FCV	BPEV
Nuclear							ICEV, FCV	BPEV

Pollutants and climate effects

Pollutant --> effects related to global climate	**CEF, mass basis (LEM)**
CO_2 --> +R	1 (reference gas)
CH_4 --> +R, -OH, +O_3 (t), +CH_4, +H_2O (s), +CO_2	23
N_2O --> +R	355
CO --> -OH, +O_3 (t), +CH_4, +CO_2	3.1 (0.6+1.0+1.6)
NMOCs --> -OH, ±O_3 (t), +CH_4, +CO_2	4.0 + 3.66· C
NO_2 --> -CO_2, +N_2O, ±OH, ±O_3 (t), ±CH_4, +PM	-1.6
SO_2 --> +PM	-15.4
PM (combustion) --> +R, clouds	46
PM (dust) --> -R, clouds	-?
CFC-12 --> +R, -O_3 (s)	7400 (9000 -1600)
HFC-134a --> +R	2000
H_2--> -OH, +O_3 (t), +CH_4	5.8 (2.4 + 3.4)
H_2O --> +R (s), +OH, -CH_4, clouds	?

Key features of the LEM

- Breadth: in addition to "core" alternative fuels for LDVs, the LEM includes materials, infrastructure, heavy-duty vehicles, public transit, electricity, heating and cooking fuels, international data, rudimentary economic parameters, and more.
- Built on detailed, original data and theoretically sound methods.
- Extensive published documentation: ~800 pages for 1993 and 1997 versions, and an additional ~800 pages for 2003 version (see www.its.ucdavis.edu/faculty/delucchi.htm).
- Can be used to model emissions impacts of complete passenger and freight transportation scenarios (done recently for developing countries in work supported by Pew).
- Beginning to incorporate price/economic effects into traditional LCA.

LEM/LCA references

- M. A. Delucchi, *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials*, UCD-ITS-RR-03-04, Institute of Transportation Studies, University of California, Davis, June (2003). With appendices. www.its.ucdavis.edu/faculty/delucchi.htm.
- M. A. Delucchi, “A Lifecycle Emissions Analysis: Urban Air Pollutants and Greenhouse-Gases from Petroleum, Natural Gas, LPG, and Other Fuels for Highway Vehicles, Forklifts, and Household Heating in The U. S.,”*World Resources Review* **13** (1): 25-51 (2001).
- M. A. Delucchi, “Transportation and Global Climate,” *Journal of Urban Technology* **6** (1): 25-46 (1999).
- M. A. DeLuchi, “Emissions from the Production, Storage, and Transport of Crude Oil and Gasoline,” *Journal of the Air and Waste Management Association* **43**: 1486-1495 (1993).

Why is LCA important?

Compare CO_2 emissions from end use vs. from the whole fuelcycle, for motor vehicles (as a % of fossil-fuel CO_2):

	•end use	•whole fuel-cycle
• **U. S.**	•22%	•30%
• **OECD-Europe**	•18%	•24%
• **World**	•14%	•19%

Source: author runs of lifecycle emissions model (LEM). Circa 1990 levels of actvity.

Emissions from Alternative-Fuel LDVs, Relative to Gasoline LDVs

	RFG	*M100*	*NG*	*H_2*	*E100*	*LPG*
CH_4 exhaust	1.00	0.50	12.0	0.10	0.50	1.00
N_2O exhaust	1.00	1.00	0.75	0.00	1.00	1.00
Fuel evap.[a]	0.85	1.00	0.20	0.20	0.50	0.25
NMOC exh.	0.70	0.90	0.24	0.10	0.90	0.50
CO exhaust	0.80	0.60	0.60	0.10	0.60	0.60
NO_2 exhaust	0.85	0.90	0.90	0.90	0.90	0.90
PM exhaust	1.00	0.40	0.20	0.00	0.40	0.25

Emissions from Alternative-Fuel HDVs, Relative to Diesel HDVs

	SD100	*M100*	*NG*	*H_2*	*E100*	*LPG*
CH_4 exhaust	0.30	0.50	30.00	0.05	0.50	1.00
N_2O exhaust	1.00	1.00	1.00	0.95	1.00	1.00
NMOC exh.	0.20	2.00	0.33	0.02	2.00	0.88
CO exhaust	0.30	1.30	0.10	0.01	1.30	0.50
NO_2 exhaust	1.30	0.50	0.50	0.50	0.50	0.50
PM exhaust	0.50	0.20	0.10	0.00	0.30	0.10

The importance of the upstream fuelcycle: upstream emissions as a percentage of end-use emissions

	RFG *oil*	diesel *oil*	LPG *oil,NG*	CNG *NG*	EtOH *corn*	EtOH *cellul.*	BD *soy*	FTD *NG*	CH2 *water*	CH2 *NG*	MeOH *NG*
CO_2	31	22	14	21	101	-14	65	34	1674	7834	42
NMOC	33	22	39	56	225	31	589	19	10	99	30
CH_4	2356	5050	1537	247	1295	491	15562	5378	3059	8727	3856
CO	4.7	8.4	3.9	3.8	20	19	248	11.6	2.8	21.2	5.1
N_2O	1.9	27.8	1.0	1.5	169	64	7736	34.4	n.a.	n.a.	3.4
NO_x	57	9	33	41	252	154	-38	11	24	80	75
SO_x	716	898	572	503	1346	108	677	175	592	904	317
PM	311	55	565	315	4444	1708	317	13	364	736	192
CO2eq	32	28	16	29	117	3	164	39	852	3801	40

Source: my runs of LEM. Based on 26 mpg LDGV, 6 mpg HDDV, year 2010 parameters. NG = natural gas, BD = biodiesel, cellul. = wood & grass.

The importance of the vehicle lifecycle: LEM estimates of emissions from materials & assembly

Pollutant	**Emissions**	**(g/lb)**	**Emissions**	**(g/mi)**	**Emissions**	**(% of end use)**
	LDGVs	*HDDVs*	*LDGV*	*HDDV*	*LDGVs*	*HDDVs*
CO_2	2,694	2,548	59.7	95.3	18.2%	5.5%
NMOCs	1.80	1.79	0.04	0.07	4.6%	4.1%
CH_4	5.98	5.49	0.13	0.21	292%	196%
CO	7.29	8.22	0.16	0.31	2.2%	1.7%
N_2O	0.08	0.08	0.00	0.00	1.3%	4.1%
NO_x	6.53	6.40	0.14	0.24	17.6%	1.1%
SO_x	6.42	6.78	0.14	0.25	147%	163.6%
PM	3.74	3.95	0.08	0.15	293%	17.5%
CO2eq	2,970	2,926	65.7	105.4	16.0%	5.5%

Source: my runs of LEM. Based on 26 mpg LDGV, 6 mpg HDDV, year 2010 parameters.

Effect of switching from IPCC GWPs to LEM CEFs

	Δ g/mi (LEM vs. IPCC)	% ch. vs base (IPCC)	% ch. vs base (LEM)
Baseline gasoline vehicle	4.8%	n.a.	n.a.
ICEV, diesel (low-sulfur)	5.6%	-30%	-29%
ICEV, natural gas (CNG)	3.6%	-25%	-26%
ICEV, LPG (P95/BU5)	4.1%	-23%	-24%
ICEV, ethanol from corn	10.9%	-14%	-9%
ICEV, ethanol from cellul.	31.3%	-81%	-76%
Battery EV, coal plants	-2.5%	-6%	-13%
Battery EV, NG plants	0.8%	-57%	-59%
FCEV, methanol from NG	0.4%	-48%	-50%
FCEV, H2 from water	3.1%	-91%	-91%
FCEV, H2 from NG	0.5%	-58%	-60%

Source: my runs of LEM. IPCC GWPs are N2O 310, CH4 21. LEM CEFs are N2O 355, CH4 23, VOCs 7, CO 3, PM 46, NOx 1.6, SOx -15

Lifecycle GHG emissions from LDVs (g/mi CO_2-equivalent and % changes)

	fuelcycle only	fuel + materials+assembly
Baseline gasoline ICEV	*541 g/mi*	*624 g/mi*
ICEV, diesel (low-sulfur)	-29%	-27%
ICEV, natural gas (CNG)	-26%	-22%
ICEV, LPG (P95/BU5)	-24%	-21%
ICEV, ethanol from corn	-9%	-8%
ICEV, ethanol from cellul.	-76%	-66%
Battery EV, coal plants	-13%	-5%
Battery EV, NG plants	-59%	-44%
FCEV, methanol from NG	-50%	-44%
FCEV, H2 from water	-91%	-79%
FCEV, H2 from NG	-60%	-52%

Source: my runs of LEM. Based on 26 mpg gasoline baseline, year 2010 parameters.

Lifecycle GHG emissions from HDVs (g/mi CO_2-equivalent and % changes)

	fuelcycle only	**fuel + materials+assembly**
Baseline diesel ICEV	*2,440 g/mi*	*2,578 g/mi*
ICEV, natural gas (CNG)	-6%	-6%
ICEV, LPG (P95/BU5)	-5%	-5%
ICEV, methanol from NG	+6%	+6%
ICEV, FTD from NG	+3%	+3%
ICEV, biodiesel from soy	+47%	+45%
ICEV, ethanol from corn	+7%	+6%
ICEV, ethanol from cellul.	-90%	-85%
FCEV, methanol from NG	-25%	-24%
FCEV, H2 from water	-86%	-82%
FCEV, H2 from NG	-38%	-37%

Source: my runs of LEM. Based on 6 mpg diesel baseline, year 2010 parameters.

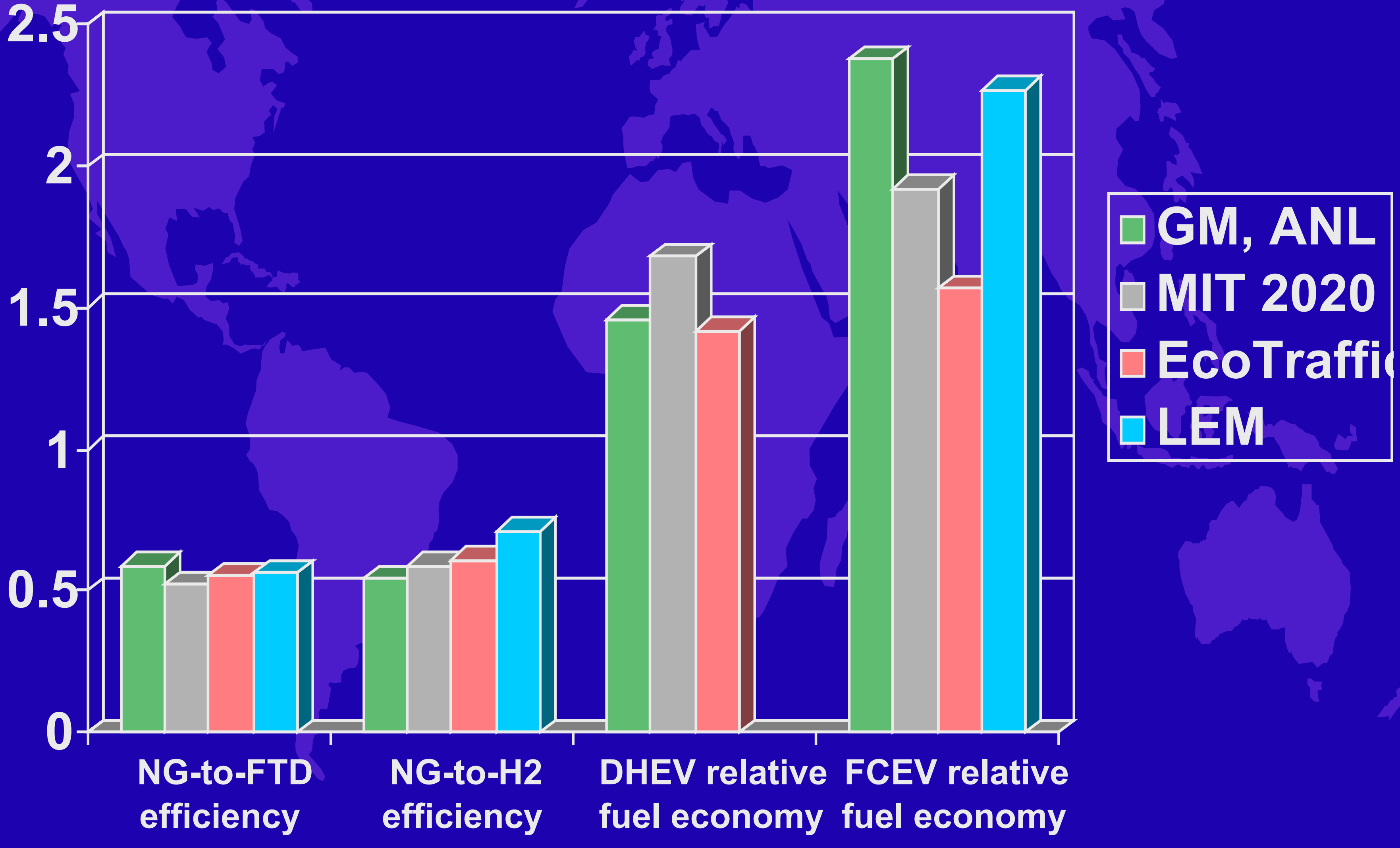
Indirect or "upstream" emissions for transit modes

- U. S. studies indicate that station and maintenance energy is ~40% of traction energy for heavy rail, and 25% for light rail. Percentage may be higher in some other countries.
- Some studies suggest that infrastructure energy is 35% of traction energy for heavy rail, and 15% for light rail.

Lifecycle GHG emissions from transport modes (gpm, % ch.)

Mode	Fuel (feedstock)	U. S.	Mexico	Chile	China	India	S. Africa
LDV	*gasoline (crude oil)*	*507*	*487*	*354*	*264*	*230*	*672*
LDV	diesel (crude oil)	-25%	-26%	-26%	-24%	-24%	-24%
LDV	ethanol (wood & grass)	-62%	-61%	-61%	-65%	-63%	-68%
LDV	electricity (national mix)	-13%	-33%	-56%	-22%	-1%	-17%
LDV	comp. H2 (NG)	-49%	-51%	-58%	-49%	-44%	-53%
bus	diesel (crude oil)	-34%	-79%	-69%	-62%	-68%	-88%
bus	F-T diesel (NG)	-32%	-79%	-68%	-62%	-68%	-88%
bus	CNG (NG)	-37%	-80%	-71%	-63%	-69%	-89%
bus	biodiesel (soy)	-8%	-71%	-59%	-46%	-52%	-84%
rail transit	heavy rail (electricity)	-67%	-85%	-80%	-46%	-12%	-86%
rail transit	light rail (electricity)	-65%	-87%	-89%	-81%	-60%	-88%
mini-bus	diesel (crude oil)	-71%	-76%	-71%	-68%	-62%	-87%
mini-bus	LPG (oil and NG)	-76%	-81%	-77%	-76%	-70%	-91%
mini-car	RFG (crude oil)	-61%	-56%	-45%	-52%	-43%	-61%
mini-car	electricity (national mix)	-78%	-75%	-79%	-67%	-48%	-73%
scooter 2-str.	gasoline (crude oil)	-69%	-63%	-50%	-32%	-52%	-74%
scooter 4-str.	RFG (crude oil)	-80%	-76%	-68%	-56%	-68%	-84%
scooter	electricity (national mix)	-81%	-78%	-79%	-50%	-56%	-80%
nonmotorized	bicycles	-95%	-95%	-93%	-88%	-89%	-96%
nonmotorized	walking	-100%	-100%	-100%	-100%	-100%	-100%

A comparison of results: estimates of energy use



Findings

- Assumptions regarding energy use of new fuel-production processes and relative energy use of advanced vehicles remain the main determinant of lifecycle emissions. (No surprise.)
- The materials lifecycle may differ significantly from one mode to another, and for BPEVs compared with ICEVs, but probably not for advanced HEVs, ICEVs, and FCEVs.
- Climatic effects of PM, SOx, and NOx may be important in some cases. (PM may have large positive CEF, but SOx may have countervailing large negative CEF.)
- Failure to consider price/economic effects may not matter much when comparing fossil-fuel-based alternatives with limited co-products, but may matter significantly in most other cases.

Overall conclusion

- Conventiona LCAs of energy use and emissions may reasonably well represent differences between similar alternatives, but needs further development to adequately represent differences between transport modes or between dissimilar fuel production pathways (such as biofuels vs. fossil fuels).

Lifecycle research areas

- Incorporation of price-dynamic economic effects of transportation policies on use of (and hence emissions from) vehicles and fuels (exploratory project wth USDOE completed).
- More detailed treatment of byproducts and coproducts (related to above).
- More detailed and better documented treatment of biomass in fuelcycles (underway; USDOE funding).
- CO2-equivalency factors for PM, SOx, and NOx.
- Incorporation of more formal treatment of uncertainty.
- Routine updating of emissions and input/output parameters.
- Better treatment of energy use and emissions associated with infrastructure.
- New vehicle/fuel pathways (e.g., HEVs, bio-derived hydrogen, carbon sequestration).

Issues in Lifecycle Analysis

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